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Comparison of clinical rating scales in genetic frontotemporal dementia within the GENFI cohort

Georgia Peakman ¹, Lucy L Russell,¹ Rhian S Convery ¹, Jennifer M Nicholas,² John C Van Swieten ³, Lize C Jiskoot ³, Fermin Moreno,^{4,5} Raquel Sanchez-Valle,⁶ Robert Laforce,⁷ Caroline Graff,^{8,9} Mario Masellis,¹⁰ Maria Carmela Tartaglia,¹¹ James B Rowe ¹², Barbara Borroni ¹³, Elizabeth Finger ¹⁴, Matthis Synofzik,^{15,16} Daniela Galimberti ^{17,18}, Rik Vandenberghe,^{19,20,21} Alexandre de Mendonça,²² Chris R Butler,^{23,24} Alex Gerhard ^{25,26}, Simon Ducharme ^{27,28}, Isabelle Le Ber ^{29,30,31}, Fabrizio Tagliavini,³² Isabel Santana,^{33,34} Florence Pasquier,^{35,36,37} Johannes Levin,^{38,39,40} Adrian Danek ³⁸, Markus Otto ⁴¹, Sandro Sorbi ^{42,43}, Jonathan D Rohrer ¹, Genetic FTD Initiative (GENFI)

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For numbered affiliations see end of article.

Correspondence to

Dr Jonathan D Rohrer, Department of Neurodegenerative Disease, University College London Dementia Research Centre, London, London, UK; j.rohrer@ucl.ac.uk

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ABSTRACT

Background Therapeutic trials are now underway in genetic forms of frontotemporal dementia (FTD) but clinical outcome measures are limited. The two most commonly used measures, the Clinical Dementia Rating (CDR)+National Alzheimer's Disease Coordinating Center (NACC) Frontotemporal Lobar Degeneration (FTLD) and the FTD Rating Scale (FRS), have yet to be compared in detail in the genetic forms of FTD.

Methods The CDR+NACC FTLD and FRS were assessed cross-sectionally in 725 consecutively recruited participants from the Genetic FTD Initiative: 457 mutation carriers (77 microtubule-associated protein tau (*MAPT*), 187 *GRN*, 193 *C9orf72*) and 268 family members without mutations (non-carrier control group). 231 mutation carriers (51 *MAPT*, 92 *GRN*, 88 *C9orf72*) and 145 non-carriers had available longitudinal data at a follow-up time point.

Results Cross-sectionally, the mean FRS score was lower in all genetic groups compared with controls: *GRN* mutation carriers mean 83.4 (SD 27.0), *MAPT* mutation carriers 78.2 (28.8), *C9orf72* mutation carriers 71.0 (34.0), controls 96.2 (7.7), $p < 0.001$ for all comparisons, while the mean CDR+NACC FTLD Sum of Boxes was significantly higher in all genetic groups: *GRN* mutation carriers mean 2.6 (5.2), *MAPT* mutation carriers 3.2 (5.6), *C9orf72* mutation carriers 4.2 (6.2), controls 0.2 (0.6), $p < 0.001$ for all comparisons. Mean FRS score decreased and CDR+NACC FTLD Sum of Boxes increased with increasing disease severity within each individual genetic group. FRS and CDR+NACC FTLD Sum of Boxes scores were strongly negatively correlated across all mutation carriers ($r_s = -0.77$, $p < 0.001$) and within each genetic group ($r_s = -0.67$ to -0.81 , $p < 0.001$ in each group). Nonetheless, discrepancies in disease staging were seen between the scales, and with each scale and clinician-judged symptomatic status. Longitudinally, annualised change in both FRS and CDR+NACC FTLD Sum of Boxes scores initially increased with disease severity level before decreasing in those with the most severe disease: controls -0.1 (6.0) for FRS, -0.1 (0.4)

for CDR+NACC FTLD Sum of Boxes, asymptomatic mutation carriers -0.5 (8.2), 0.2 (0.9), prodromal disease -2.3 (9.9), 0.6 (2.7), mild disease -10.2 (18.6), 3.0 (4.1), moderate disease -9.6 (16.6), 4.4 (4.0), severe disease -2.7 (8.3), 1.7 (3.3). Sample sizes were calculated for a trial of prodromal mutation carriers: over 180 participants per arm would be needed to detect a moderate sized effect (30%) for both outcome measures, with sample sizes lower for the FRS.

Conclusions Both the FRS and CDR+NACC FTLD measure disease severity in genetic FTD mutation carriers throughout the timeline of their disease, although the FRS may be preferable as an outcome measure. However, neither address a number of key symptoms in the FTD spectrum, for example, motor and neuropsychiatric deficits, which future scales will need to incorporate.

INTRODUCTION

Frontotemporal dementia (FTD) is a spectrum of heterogeneous disorders characterised by neurodegeneration of the frontal and temporal lobes. A total of 20%–30% of FTD cases are genetic,^{1,2} with the majority caused by autosomal dominant mutations in three genes: chromosome 9 open reading frame 72 (*C9orf72*),⁴ progranulin (*GRN*)⁵ and microtubule-associated protein tau (*MAPT*).⁶ Clinical syndromes span changes in behaviour (behavioural variant FTD, bvFTD),⁷ language (primary progressive aphasia, PPA)⁸ and motor function (progressive supranuclear palsy, PSP, corticobasal syndrome, CBS and FTD with amyotrophic lateral sclerosis, FTD-ALS).^{9–11} Age of symptom onset, and disease progression and duration vary between and within genetic groups.¹²

The ability to accurately evaluate disease stage and track clinical change in FTD across the spectrum of phenotypes is critical for the design of future trials of disease-modifying therapies. Two candidate global severity measures specific to FTD are the Clinical Dementia Rating (CDR) Dementia

Staging Instrument and the FTD Rating Scale (FRS). The CDR is a widely used scale that was developed to stage the severity of dementia in the Alzheimer's Disease spectrum.^{13 14} Impairment in six cognitive and functional domains are assessed by a neurologist through semistructured interview with both the patient and caregiver. The CDR was extended for FTD by introducing a behaviour and a language domain, taken from the National Alzheimer's Disease Coordinating Centre (NACC) Frontotemporal Lobar Degeneration (FTLD) module (CDR+NACCFTLD).^{15 16} A version of the global CDR scoring system¹⁷ (without the emphasis on the memory domain) has been developed to apply to the CDR+NACCFTLD, which classifies cases into five severity levels based on the number and severity of the ratings given for the eight domains.¹⁸ The CDR+NACCFTLD has shown ability to detect mild to severe symptoms in sporadic and genetic FTD cohorts^{15 16 18 19} and capture disease progression over 1–2 years.^{15 20} The FRS is a 30-item caregiver questionnaire developed with the aim of staging FTD severity based on behavioural changes and functional decline.²¹ The scale captures six levels of impairment from very mild to profound. Disease severity according to the FRS has been found to correlate with the CDR^{21 22} and CDR+NACCFTLD,²³ but a detailed evaluation of the measure across the range of presymptomatic and symptomatic FTD has not been reported.

Few studies have directly compared the FRS and CDR+NACCFTLD staging tools, particularly in relation to the increasingly used CDR+NACCFTLD global scoring system. The objectives of this study were to: (1) evaluate and compare how the FRS and CDR+NACCFTLD scales characterise disease stage and severity in the spectrum of presymptomatic and symptomatic genetic FTD, using cross-sectional data from the Genetic FTD Initiative (GENFI) cohort; (2) examine and compare longitudinal change in the scales using data at 1-year follow-up and (3) estimate the sample sizes required to detect a small or moderate size effect on disease progression based on the two candidate outcome measures.

METHODS

Cohort

From the fifth data freeze of the GENFI study, 725 participants with both FRS and CDR+NACCFTLD data available for at least one time point were included in the study: 457 mutation carriers (77 *MAPT*, 187 *GRN*, 193 *C9orf72*) and 268 family members without mutations (non-carrier control group).

Measures

All participants underwent a standardised history and examination including the Mini-Mental State Examination (MMSE), with symptomatic status judged by the assessing clinician according to consensus diagnostic criteria.

Frontotemporal dementia Rating Scale (FRS)

The FRS is a 30-item questionnaire covering seven areas: behaviour, outing and shopping, household chores and telephone, finances, medications, meal preparation and eating, and self care and mobility. The FRS was completed by an informant (family member or caregiver) by rating the frequency of difficulties in these areas ('all the time', 'sometimes', 'never'). Raw scores are converted to a percentage (total number of 'never' responses/total number of applicable questions) to exclude any items that were not applicable to the patient. Lower percentage scores therefore denote greater impairment of everyday abilities

and behavioural change. In the original development of the scale, six severity stages were identified and operationalised in 75 patients with FTD (very mild, 100%–97%; mild, 96%–80%; moderate, 79%–41%; severe, 40%–13%; very severe, 12%–3%; profound, 2%–0%).²¹ One modification was made to these classifications for use in the GENFI cohort because the FRS is also collected on non-carrier family members: a score of 100% was considered 'asymptomatic' rather than 'very mild'. The 'very mild' category in this study therefore encompasses scores of 97%–99% instead of 97%–100%.

CDR+NACC-FTLD

The eight domains of the CDR+NACCFTLD assess memory, orientation, judgement and problem solving, community affairs, home and hobbies, personal care, overall behaviour and overall language. Based on a semistructured interview with the patient and an informant, the presence of impairment in each of these domains is rated by a clinician using scores of 0 (absent), 0.5 (questionable/very mild), 1 (mild), 2 (moderate) and 3 (severe).^{15–17} The sum of boxes score (CDR+NACC-FTLD-SB) is calculated by summing the ratings given for the eight domains. Thus, a higher sum of boxes value denotes greater symptomatology. The CDR+NACCFTLD global rating was determined using the published scoring rules,¹⁸ whereby a rating on a five-point scale is given (0, 0.5, 1, 2, 3) based on the severity of the ratings given for the eight domains. All eight domains are given equal weighting when calculating the global score, so it does not relate to a specific FTD variant, and if any domain has a rating above 0 then the global score is at least 0.5. Therefore, cases with no impairment in any domain are given a global rating of 0, those with mild cognitive, behavioural or language impairment are rated 0.5, those with mild but definite symptomatology are intended to receive a rating of 1, those with moderate dementia 2 and severe dementia 3. Global ratings can be reduced into three broader disease severity levels: normal or asymptomatic (0), very mild or prodromal cognitive, behavioural or language impairment (0.5) and fully symptomatic (≥ 1).¹⁸

Statistical analysis

Descriptive statistics and group comparisons

Data were analysed using SPSS V.26 or STATA V.16. Demographic variables were compared between groups using independent sample t-tests or Mann-Whitney U tests when $n < 30$. Sex was compared between groups using χ^2 tests. A linear regression model was used to compare both FRS and CDR+NACC-FTLD-SB scores between groups; bootstrapping with 1000 repetitions was used for data that were not normally distributed. Correlations between FRS percentage score and CDR+NACCFTLD Sum of Boxes scores were generated using Spearman rank correlation coefficients (two-tailed), as were correlations of both scales with disease duration (years since clinician-judged symptom onset – analysis restricted to symptomatic participants) and MMSE score.

Longitudinal analyses

Of the baseline sample, 231 mutation carriers (51 *MAPT*, 92 *GRN*, 88 *C9orf72*) and 145 non-carriers had FRS and CDR+NACCFTLD data available at a follow-up time point. Mean time between baseline and follow-up was 1.3 years (SD=0.5). For both scales, annualised change was calculated as: [follow-up score] - [baseline score]/time between baseline and follow-up. Annualised change was compared between the mutation carrier group and controls

Table 1 Baseline demographic and clinical characteristics of study cohort by genetic group

	GRN mutation carriers	MAPT mutation carriers	C9orf72 mutation carriers	Controls
N	187	77	193	268
Age (years)	50.8 (13.6)	45.5 (13.8)	51.5 (13.8)	46.4 (12.9)
Sex (% female)	60.4	54.5	50.8	58.6
Education (years)	14.0 (3.7)	14.1 (3.4)	13.9 (3.3)	14.5 (3.3)
CDR				
CDR Sum of Boxes	1.9 (4.1)	2.4 (4.4)	3.1 (4.9)	0.1 (0.4)
CDR+NACC FTLD Sum of Boxes	2.6 (5.2)	3.2 (5.6)	4.2 (6.2)	0.2 (0.6)
CDR+NACC-FTLD-Global (% of participants)				
0	61.0	54.5	47.7	80.2
0.5	13.4	16.9	16.6	17.5
1	10.2	9.1	9.3	2.2
2	8.0	10.4	13.5	0.0
3	7.5	9.1	13.0	0.0
FRS				
Percentage score (0–100)	83.4 (27.0)	78.2 (28.8)	71.0 (34.0)	96.2 (7.7)
Severity category (% of participants)				
Asymptomatic	48.1	37.7	29.0	61.6
Very mild	7.5	7.8	6.7	10.8
Mild	19.3	22.1	24.9	23.5
Moderate	13.9	13.0	12.4	4.1
Severe	8.6	15.6	18.1	0.0
Very severe	2.7	3.9	7.8	0.0
Profound	0.0	0.0	1.0	0.0

Values are mean (SD) unless stated.

CDR+NACC FTLD= CDR Dementia Staging Instrument plus Behaviour and Language domains from the NACC FTLD module.

CDR, Clinical Dementia Rating; FRS, Frontotemporal dementia Rating Scale; FTLD, Frontotemporal Lobar Degeneration; MAPT, microtubule-associated protein tau; NACC, National Alzheimer's Disease Coordinating Center.

using a linear regression model; bootstrapping with 1000 repetitions was used for data that were not normally distributed.

Sample size calculation

To explore the use of the FRS and CDR+NACC-FTLD-SB scores as potential outcome measures in treatment trials, sample sizes per arm of a two-arm trial of a disease modifying therapy (with 1:1 randomisation to placebo vs active treatment) were calculated using an analysis of covariance method. The analysis focused on mutation carriers with a baseline CDR+NACCFTLD global rating of 0.5 (ie, a prodromal trial), with the desired treatment effect hypothesised as a reduction in progression from the mean score of the outcome measure in the global 0.5 CDR+NACCFTLD group to the mean score of the outcome measure in the global 1 CDR+NACCFTLD group, that is, slowing of progression from prodromal to fully symptomatic. The following formula was used:

$$n = (1 - p^2) \frac{2\sigma^2}{\delta^2} f(\alpha, \beta) \text{ where } f(\alpha, \beta) = (z_{1-\alpha/2} + z_{1-\beta})^2$$

ρ is the correlation between baseline and follow-up scores of the outcome measure in mutation carriers, σ is the SD of scores at follow-up, δ is the treatment effect (difference in mean score between the prodromal (0.5) group and mild symptomatic (1) group), α is the significance level, set at 0.05. and $1 - \beta$ is the power to detect a treatment effect, set at $\beta=0.2$ ie, that is, power 80%.

RESULTS

Demographics

The demographic and clinical characteristics of the participants in each genetic group at their baseline time point are summarised in [table 1](#). The groups shared similar demographic profiles,

except that the *MAPT* mutation carriers and the controls were younger than the *C9orf72* mutation carriers (*MAPT* $t=-3.207$, $p=0.002$; controls $t=-4.030$, $p<0.001$) and *GRN* mutation carriers (*MAPT* $t=-2.875$, $p=0.004$; controls $t=-3.501$, $p=0.001$).

Defining disease severity in the mutation carriers by CDR+NACCFTLD global rating, 54.3% were asymptomatic (CDR+NACCFTLD global=0), 15.3% had a prodromal phenotype (0.5) and 30.4% had a symptomatic phenotype (≥ 1).

Cross-sectional change in the FRS and CDR+NACC-FTLD

Comparison of both FRS and CDR+NACC-FTLD-SB between groups

The mean FRS% score in all genetic groups was lower than controls ($p<0.001$ for all comparisons): *GRN* mutation carriers mean 83.4 (SD 27.0), *MAPT* mutation carriers 78.2 (28.8), *C9orf72* mutation carriers 71.0 (34.0), controls 96.2 (7.7) ([table 1](#) and online supplemental table 1). There was also a significant difference between the *C9orf72* group and both the *GRN* group ($p<0.001$) and the *MAPT* group ($p=0.032$).

The mean CDR+NACC-FTLD-SB score was higher in all genetic groups compared with controls (all $p<0.001$): *GRN* mutation carriers mean 2.6 (5.2), *MAPT* mutation carriers 3.2 (5.6), *C9orf72* mutation carriers 4.2 (6.2), controls 0.2 (0.6) ([table 1](#), online supplemental table 2). A significant difference was seen between the *C9orf72* and *GRN* groups ($p=0.001$).

Comparison of both FRS and CDR+NACC-FTLD-SB within genetic groups by disease severity

Mean scores on the FRS according to CDR+NACCFTLD severity level (0, 0.5, ≥ 1) for each genetic group are reported in [table 2](#), and according to individual CDR+NACCFTLD global

Table 2 Baseline FRS scores according to CDR+NACC FTLD severity level, by genetic group

CDR+NACC FTLD Global Group	GRN mutation carriers			MAPT mutation carriers			C9orf72 mutation carriers			Controls
	0	0.5	≥1	0	0.5	≥1	0	0.5	≥1	
N	114	25	48	42	13	22	92	32	69	268
FRS % Score	97.4 (5.7)	90.9† (14.2)	46.3*, †, ‡ (28.1)	93.0 (11.2)	89.7 (18.9)	43.0*, †, ‡ (27.1)	94.9 (8.2)	85.0*, † (20.2)	32.7*, †, ‡ (25.0)	96.2 (7.7)
CDR+NACC FTLD Sum of Boxes	0.0 (0.0)	1.0*, † (0.8)	9.7*, †, ‡ (6.2)	0.0 (0.0)	1.1 (0.8)*, †	10.5*, †, ‡ (5.9)	0.0 (0.0)	1.1*, † (0.7)	11.1*, †, ‡ (5.5)	0.2 (0.6)

Values are mean (SD) unless stated.

CDR+NACC FTLD=CDR Dementia Staging Instrument plus Behaviour and Language domains from the NACC FTLD module.

CDR+NACC FTLD sum of boxes scores are also shown in the same groups for comparison.

*P<0.05 versus controls.

†P<0.05 versus CDR+NACC-FTLD Global score=0 group (within the same genetic group).

‡P<0.05 versus CDR+NACC-FTLD Global score=0.5 group (within the same genetic group).

CDR, Clinical Dementia Rating; FRS, Frontotemporal dementia Rating Scale; FTLD, Frontotemporal Lobar Degeneration; NACC, National Alzheimer's Disease Coordinating Center.

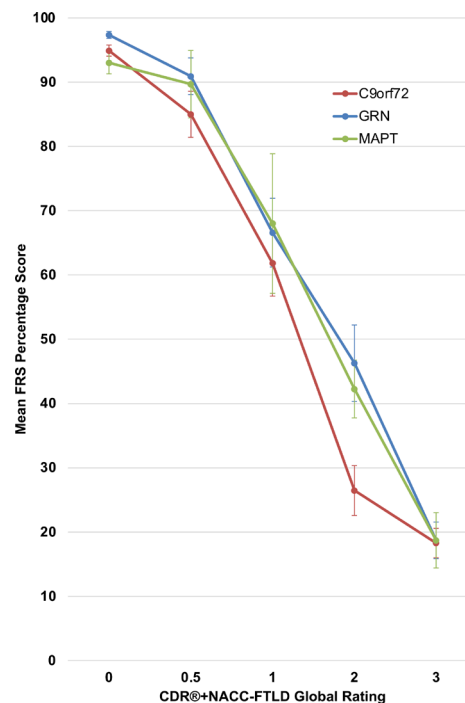


Figure 1 Mean FRS percentage score according to CDR+NACC FTLD global rating in mutation carriers at baseline. Error bars represent SE of the mean. CDR+NACC FTLD global ratings: GRN 0, N=114; 0.5, N=25; 1, N=19; 2, N=15; 3, N=14; MAPT 0, N=42; 0.5, N=13; 1, N=7; 2, N=8; 3, N=7; C9orf72 0, N=92; 0.5, N=32; 1, N=18; 2, N=26; 3, N=25. CDR, Clinical Dementia Rating; FRS, Frontotemporal dementia Rating Scale; NACC, National Alzheimer's Disease Coordinating Center.

rating (0–3) are presented in [figure 1](#). GRN, MAPT and C9orf72 mutation carriers with a global rating of 0 had comparable FRS scores to controls (online supplemental table 3). Within both the GRN and C9orf72 mutation carriers, the mean FRS score was significantly lower in cases with a global rating of 0.5 compared with those with 0. Within every genetic group, the cases with a global rating of ≥1 had significantly lower FRS scores than those with 0 or 0.5.

For comparison, mean CDR+NACC-FTLD-SB scores according to severity level for each genetic group are also reported in [table 2](#). The mean CDR+NACC-FTLD-SB scores were higher in those with a global rating of 0.5 and ≥1 than either controls or those with a global rating of 0 in all three genetic groups (online supplemental table 4).

Correlation of FRS and CDR+NACC-FTLD-SB

In the mutation carriers as a whole, FRS and CDR+NACC-FTLD-SB scores were strongly negatively correlated ($r_s = -0.77$, $p < 0.001$) ([figure 2](#)). Similar associations were found in the individual genetic groups: GRN mutation carriers ($r_s = -0.75$, $p < 0.001$); MAPT mutation carriers ($r_s = -0.67$, $p < 0.001$); C9orf72 mutation carriers ($r_s = -0.81$, $p < 0.001$) (online supplemental figure 1).

Comparison of FRS and CDR+NACC-FTLD-SB by severity categories

The percentage of mutation carriers in each FRS severity category according to their CDR+NACC FTLD global rating, and vice versa, are shown in [figure 3](#) (and individually for GRN, MAPT and C9orf72 mutation carriers in online supplemental figure 2). Mutation carriers who had an FRS score in the 'asymptomatic' range most frequently had a global rating of 0 (84.0%); cases in the 'very mild' FRS category also predominantly had

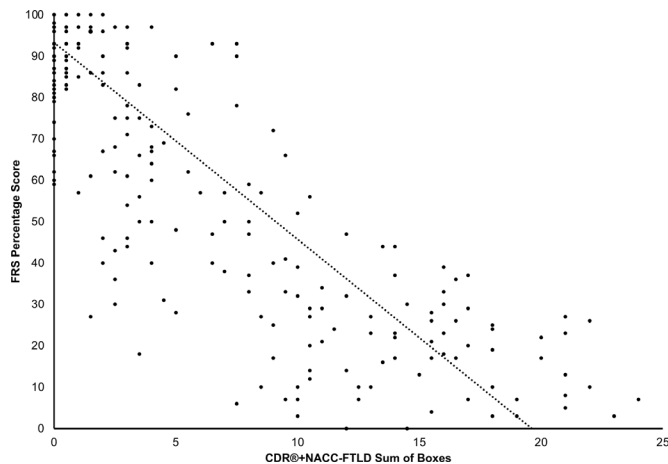
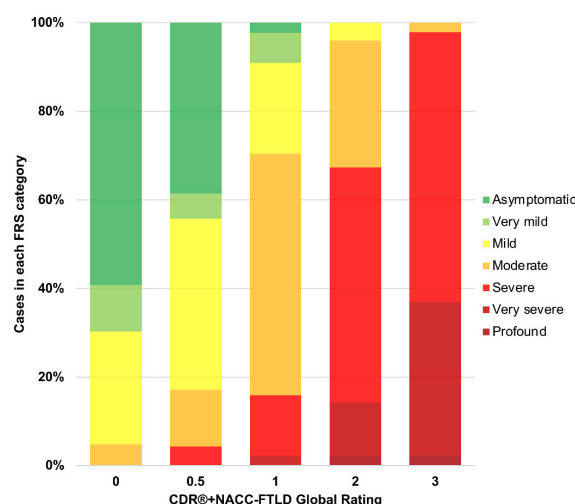


Figure 2 Scatter plot of FRS percentage scores and CDR+NACC FTLD sum of boxes scores in all mutation carriers at baseline. CDR, Clinical Dementia Rating; FRS, Frontotemporal dementia Rating Scale; NACC, National Alzheimer's Disease Coordinating Center.

a global rating of 0 (78.8%); the 'mild' category encompassed cases with mostly global ratings of 0 (62.4%) or 0.5 (26.7%); the 'moderate' category covered cases with global ratings of 0 (20.0%), 0.5 (15.0%), 1 (40.0%) and 2 (23.3%); the 'severe' category mostly included ratings of 2 (41.3%) or 3 (44.4%); the 'very severe' category encompassed ratings of largely 3 (69.6%) as well as 2 (26.1%); and of the two participants who had an FRS score in the 'profound' range, one had a global rating of 2 (50%) and the other 3 (50%).

Frequency and severity of individual CDR+NACC-FTLD domains within each FRS severity category

The frequency of abnormal ratings (≥ 0.5) on the individual domains of the CDR+NACCFTLD within each FRS severity level are shown in [figure 4A](#) for mutation carriers and controls, and for the individual genetic groups in online supplemental figure 3A. Memory was the most commonly affected domain in the asymptomatic, very mild and mild FRS severity levels in both non-carriers and carriers.



The mean ratings for the CDR+NACCFTLD domains (ie, the severity) in each of the FRS levels are shown in [figure 4B](#) for mutation carriers and controls, and for the individual genetic groups in online supplemental figure 3B. Comparing the mean domain score of mutation carriers at each FRS stage against the mean score in controls for that domain: in the asymptomatic and very mild FRS stages, none of the domains were different from controls; in the mild stage, the memory ($p=0.009$), community affairs ($p=0.040$) and behaviour ($p=0.002$) domains had higher ratings than controls; and in the moderate, severe and very severe/profound FRS stages, all of the CDR+NACCFTLD domains had more severe ratings than controls.

Correlation of both FRS and CDR+NACC-FTLD-SB with other measures of disease severity

The FRS score was moderately negatively correlated with disease duration in symptomatic participants except in *C9orf72* mutation carriers (all symptomatic participants $r_s = -0.383$, $p < 0.001$; *GRN* $r_s = -0.541$, $p < 0.001$; *MAPT* $r_s = -0.525$, $p = 0.008$; *C9orf72* $r_s = -0.201$, $p = 0.078$), and positively correlated with MMSE score (all mutation carriers $r_s = 0.614$, $p < 0.001$; *GRN* $r_s = 0.654$, $p < 0.001$; *MAPT* $r_s = 0.623$, $p < 0.001$; *C9orf72* $r_s = 0.558$, $p < 0.001$).

The CDR+NACC-FTLD-SB score was also moderately positively correlated with increased disease duration in symptomatic participants (all symptomatic participants $r_s = 0.426$, $p < 0.001$; *GRN* $r_s = 0.518$, $p < 0.001$; *MAPT* $r_s = 0.529$, $p = 0.008$; *C9orf72* $r_s = 0.330$, $p = 0.003$), and negatively correlated with MMSE score (all mutation carriers $r_s = -0.646$, $p < 0.001$; *GRN* $r_s = -0.638$, $p < 0.001$; *MAPT* $r_s = -0.685$, $p < 0.001$; *C9orf72* $r_s = -0.618$, $p < 0.001$).

Comparison of both FRS and CDR+NACC-FTLD-SB with clinician judgment of diagnosis

The number of participants judged to be symptomatic by clinicians was 152: 103 bvFTD⁷ (27 *GRN*, 21 *MAPT*, 55 *C9orf72*), 24 PPA⁸ (20 *GRN*, 1 *MAPT*, 3 *C9orf72*), 16 ALS or FTD-ALS²⁴ (all *C9orf72*), 4 with parkinsonian disorders^{10 11} (2 *GRN*, 1 *MAPT*, 1 *C9orf72*), and five diagnosed with a dementia not otherwise specified (1 *GRN*, 1 *MAPT*, 3 *C9orf72*).

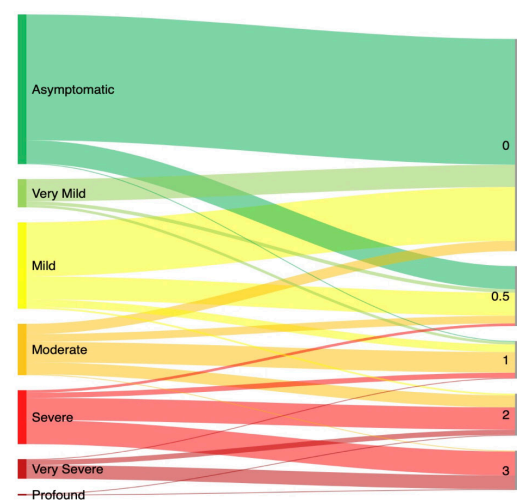


Figure 3 Bar graph and Sankey diagram presenting proportions of participants in each FRS severity category according to CDR+NACC FTLD global rating, in all mutation carriers at baseline. CDR+NACC FTLD global rating 0, N=248; 0.5, N=70; 1, N=44; 2, N=49; 3, N=46. CDR, Clinical Dementia Rating; FRS, Frontotemporal dementia Rating Scale; NACC, National Alzheimer's Disease Coordinating Center.

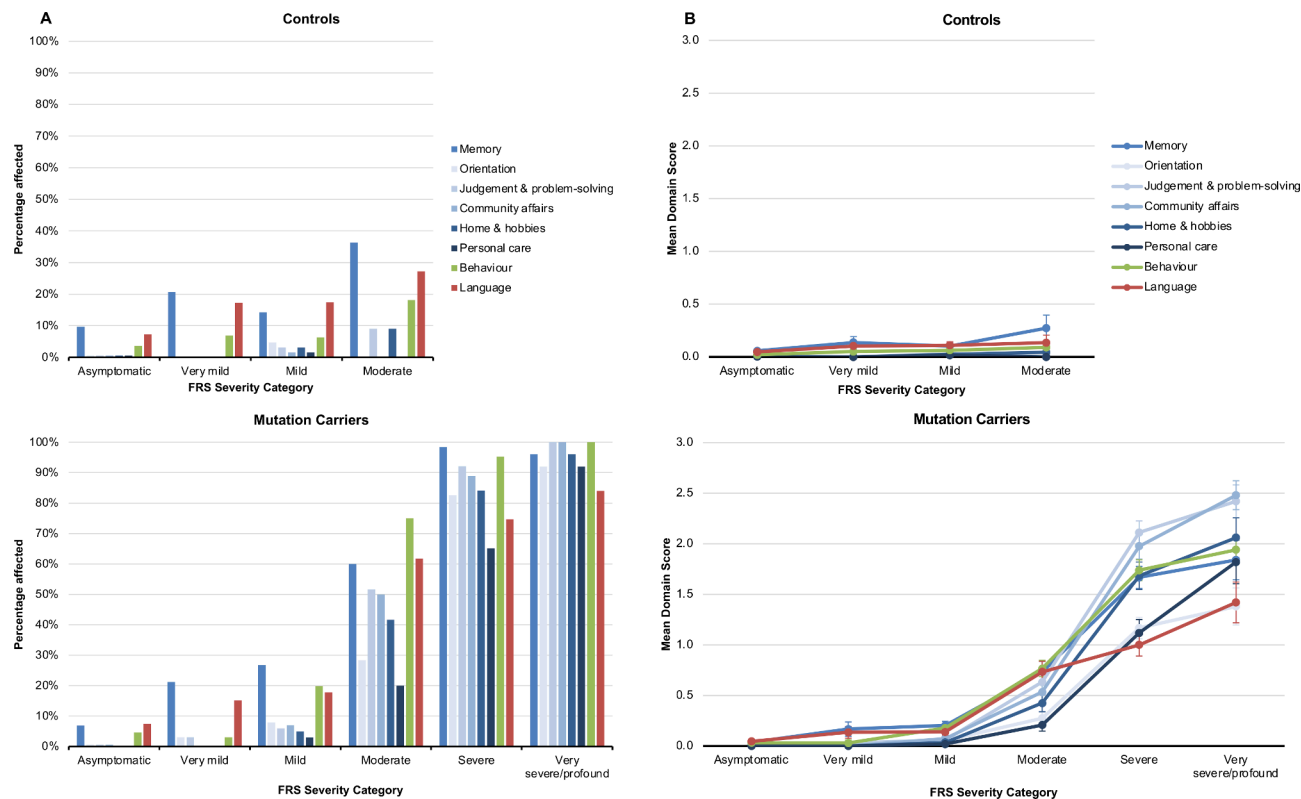


Figure 4 (A) Frequencies of CDR+NACC FTLD domains affected (rating ≥ 0.5) within each FRS severity category, in mutation carriers and non-carrier controls at baseline. FRS severity categories: controls: asymptomatic, N=165; very mild, N=29; mild, N=63; moderate, N=11; severe, N=0; very severe, N=0; profound, N=0; mutation carriers: asymptomatic, N=175; very mild, N=33; mild, N=101; moderate, N=60; severe, N=63; very severe, N=23; profound, N=2. Note that very severe and profound groups were combined for the mutation carriers due to limited cases in the profound group. (B) Mean scores on CDR+NACC FTLD domains within each FRS severity category, in mutation carriers and in non-carrier controls at baseline. Error bars represent SE of the mean. domains are rated using scores of 0 (absent), 0.5 (questionable/very mild), 1 (mild), 2 (moderate) and 3 (severe). CDR, Clinical Dementia Rating; FRS, Frontotemporal dementia Rating Scale; NACC, National Alzheimer's Disease Coordinating Center.

The distributions of these diagnoses across the FRS severity categories and CDR+NACCFTLD global rating groups are shown in online supplemental table 5. Both rating scales classified four participants who had been judged as symptomatic within the lowest severity category (asymptomatic for FRS: 2 bvFTD, 1 PPA, 1 ALS/FTD-ALS; 0 for CDR+NACC-FTLD: 1 bvFTD, 2 ALS/FTD-ALS, 1 with a parkinsonian disorder). With increasing FRS severity and CDR+NACCFTLD global rating, an increasingly larger number of participants were judged to be symptomatic: by FRS severity – very mild 6.5%, mild 9.8%,

moderate 60.6%, severe 95.2%, very severe/profound 100.0%; by CDR+NACCFTLD global rating – 0.5 16.2%, 1 70.0%, 2 98.0%, 3 100.0%.

Longitudinal change in the FRS and CDR+NACC-FTLD

Annualised change on the FRS and CDR+NACC-FTLD-SB in controls and according to baseline CDR+NACCFTLD severity level in mutation carriers are reported in table 3 and online supplemental table 6 and shown in figure 5. Annualised change in FRS

Table 3 Annualised change in FRS percentage and CDR+NACC FTLD sum of boxes scores in mutation carriers according to baseline CDR+NACC FTLD global rating, and non-carrier controls

CDR+NACCFTLD global rating at baseline	Mutation carriers					Controls
	0	0.5	1	2	3	
N	140	30	22	23	16	145
FRS % Score						
Annualised change	−0.5 (8.2)	−2.3 (9.9)	−10.2 (18.6)*, †	−9.6 (16.6)*, †	−2.7 (8.3)	−0.1 (6.0)
CDR+NACC-FTLD-SB						
Annualised change	0.2 (0.9)*	0.6 (2.7)	3.0 (4.1)*, †, ‡	4.4 (4.0)*, †, ‡, §	1.7 (3.3)*	−0.1 (0.4)

Values are mean (SD) unless stated.

CDR+NACC FTLD=CDR Dementia Staging Instrument plus Behaviour and Language domains from the NACC FTLD module.

*P<0.05 versus controls

†P<0.05 versus baseline CDR+NACCFTLD global rating=0

‡P<0.05 versus baseline CDR+NACCFTLD global rating=0.5

§P<0.05 versus baseline CDR+NACCFTLD global rating=3.

CDR, Clinical Dementia Rating; FRS, Frontotemporal dementia Rating Scale; FTLD, Frontotemporal Lobar Degeneration; NACC, National Alzheimer's Disease Coordinating Center.

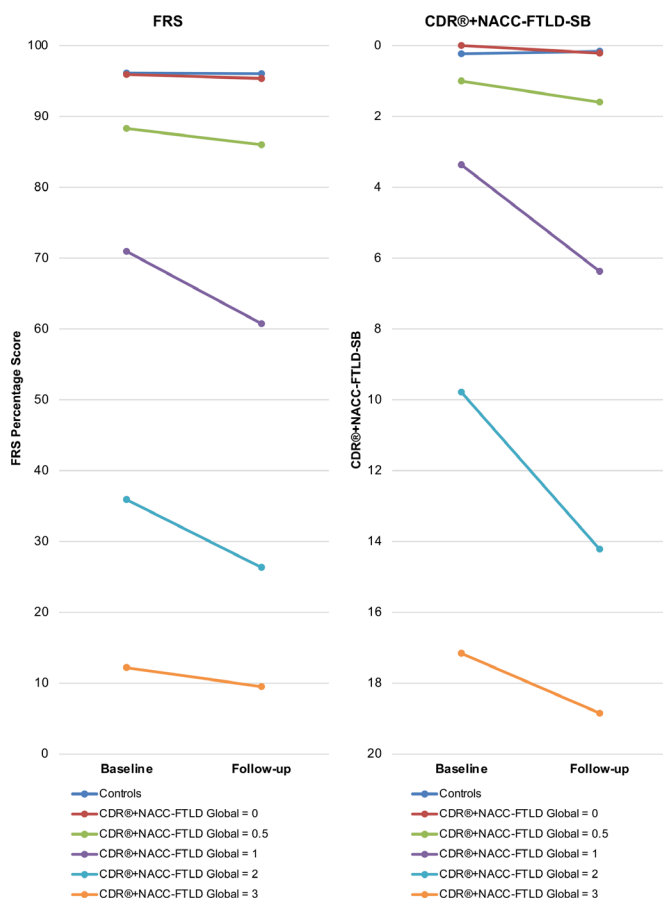


Figure 5 Annualised change in FRS percentage score and CDR+NACC-FTLD sum of boxes score in mutation carriers according to baseline CDR+NACC-FTLD global rating and controls. Baseline values=mean score, follow-up values=(baseline mean score)+(mean annualised change in score). Controls N=145; carriers N=232 (baseline CDR+NACC-FTLD global 0, N=140; 0.5, N=30; 1, N=22; 2, N=23; 3, N=16). CDR, Clinical Dementia Rating; FRS, Frontotemporal dementia Rating Scale; NACC, National Alzheimer's Disease Coordinating Center.

and CDR+NACC-FTLD-SB scores initially increased with global severity level and was greatest in carriers with symptomatic baseline global ratings of 1 or 2 before decreasing in cases with a global rating of 3. Mutation carriers with global ratings of 1 or 2 were the only groups to show change on the FRS over 1 year that significantly exceeded controls ($p=0.011$ and 0.005 , respectively). On the CDR+NACC-FTLD, annualised change in the Sum of Boxes score exceeded controls in each of the global severity levels except in the 0.5 group (0 group vs controls, $p=0.001$, 0.5 group vs controls, $p=0.202$, 1 group vs controls, $p=0.001$, 2 group vs controls ($p<0.001$, 3 group vs controls, $p=0.033$).

Sample size calculations

Table 4 shows the number of participants required to demonstrate efficacy on change in FRS percentage score and CDR+NACC-FTLD Sum of Boxes score as potential outcome measures when assuming small (10%) to moderate (30%) effect sizes. For a trial entering prodromal mutation carriers (with a global rating of 0.5), over 180 participants per arm would be needed to detect a moderate sized effect (30%) for both outcome measures. Power calculations using the FRS yielded projected sample sizes that were more favourable than the CDR+NACC-FTLD Sum of Boxes.

Table 4 Sample sizes for small to moderate effect sizes on progression in mean FRS percentage score and mean CDR+NACC-FTLD Sum of Boxes score, in mutation carriers with a global rating of 0.5

	Effect size on progression in mean score				
	30%	25%	20%	15%	10%
FRS percentage score					
N (per arm)	181	261	408	725	1630
CDR+NACC-FTLD Sum of Boxes score					
N (per arm)	329	474	740	1315	2960

CDR+NACC-FTLD=CDR Dementia Staging Instrument plus Behaviour and Language domains from the NACC FTLD module.

CDR, Clinical Dementia Rating; FRS, Frontotemporal dementia Rating Scale; FTLD, Frontotemporal Lobar Degeneration

; NACC, National Alzheimer's Disease Coordinating Center.

As the treatment effect is based on preventing progression from global CDR+NACC-FTLD 0.5–1, the length of the trial depends on the natural history of this progression. A survival analysis in the GENFI cohort previously showed that ~50% of mutation carriers progress from a global rating of 0.5–1 in 3 years (Poos *et al* in submission). Against this background, a 6-year trial of prodromal mutation carriers would therefore be required to detect the proposed treatment effect (eg, for a 30% effect on FRS, N=181), or a 3-year trial of the same treatment would require the sample size equivalent to assuming half the percentage change in the target value (eg, if there was a 30% effect on FRS, as only 50% of people will have progressed, the sample size would be equivalent to a 15% effect on FRS that is, N=725).

DISCUSSION

This study has systematically evaluated and compared disease staging and progression defined by the FRS against the widely used CDR+NACC-FTLD scale in a large cohort covering the spectrum of genetic FTD. Scores on both scales are strongly related to disease severity in FTD, and in *GRN*, *C9orf72* and *MAPT* mutation carriers, FRS scores decreased with progression while CDR+NACC-FTLD-SB increased. In direct comparison, both scores were strongly correlated with each other in all three genetic groups.

However, disease staging and severity were not entirely consistent between the two scales. Analysis indicated that the FRS might capture more subtle changes associated with disease progression. A notable proportion of cases were asymptomatic according to the CDR+NACC-FTLD (zero cognitive, behavioural or language impairments recorded) despite a mild or moderate degree of functional and/or behavioural change being reported via the FRS questionnaire. Vice versa, a number of cases with a global rating of 0.5, or in a small number a rating of 1, scored 100% on the FRS (indicating zero behavioural or functional changes). In line with previous studies,^{22,23} our data suggest that the CDR+NACC-FTLD may be more likely to underestimate disease severity when compared with FRS scores: 41% of cases with an asymptomatic CDR+NACC-FTLD global rating had a degree of disability or behavioural change according to the FRS, vs 16% of cases with an asymptomatic FRS score having some symptomatology according to the CDR+NACC-FTLD. Although the scales both broadly centre around everyday functioning and behaviour, there are differences between them e.g. the CDR+NACC-FTLD evaluates language impairment, which the FRS lacks, but conversely, the CDR+NACC-FTLD may not as comprehensively capture other changes apparent to the

caregiver, for example, behaviour is captured as a single domain in the CDR+NACCFTLD which may underestimate social and personality impairments that rely on subjective report and are difficult to operationalise. Another consideration is that several of the activities of daily living probed by the FRS have the potential to be affected by apathy or depression (four items begin with 'Lacks interest in... (activity)'), which are symptoms less relevant to the domains of the CDR+NACCFTLD. Whether depressive symptoms are directly related to evolving FTD pathology or are distinct and related to the impact of living at-risk of FTD is challenging to disentangle. Responses to the individual items of the FRS questionnaire were not available in the GENFI cohort to enable exploring trends among the cases with discrepant FRS and CDR+NACCFTLD scores, but this is a consideration for future studies of the scales.

There were also discrepancies seen between both scales and symptomatic status, with a small number of participants being judged to be symptomatic by clinicians despite an asymptomatic or very mild score on the two scales. This may relate at least in part to a further issue with both scales, which is the lack of an assessment for motor or neuropsychiatric symptoms. Parkinsonian symptoms are seen across all of the genetic forms of FTD,²⁵ while ALS is seen mainly in those with *C9orf72* mutations. Such motor deficits are associated with disease progression,²⁶ and impact on function in genetic FTD but are poorly captured by the FRS²⁷ and not measured at all in the CDR+NACCFTLD. In this cohort, half of the participants diagnosed with ALS/FTD-ALS were in the asymptomatic, very mild or mild FRS severity categories or had asymptomatic (0) or very mild (0.5) CDR+NACCFTLD global ratings. Similarly, neuropsychiatric symptoms are also prevalent across the different forms of genetic FTD,^{28 29} particularly in carriers of the *C9orf72* expansion where they can be a defining feature.^{30 31} Neither of the scales directly measure these features (ie, hallucinations, delusions, etc) and therefore are likely to be underestimating any effect of such symptoms on function and disease progression. Overall, given the heterogeneity in clinical presentation and disease course within people that share the same underlying genetic cause,¹² the inclusion of assessments of motor and neuropsychiatric symptomatology into clinical rating scales will be important for achieving accurate evaluation of disease stage. In turn, this will allow the full spectrum of FTD phenotypes to be included within the same clinical trial.

To evaluate the scale's abilities to track progression, annualised change was analysed in the cases with a follow-up time point, stratified by global impairment at baseline according to the CDR+NACCFTLD. On both scales, change over 1 year is small in the prodromal stages and then accelerates in carriers with a global rating considered to be symptomatic. Previous studies have reported significant changes in CDR+NACCFTLD scores over 1¹⁵ and 2 years²⁰ in patients with FTD. We found that annualised change also accelerated moving from an asymptomatic global rating to a very mild 0.5 rating, and moving from 0.5 to 1. Our data align with previous findings that the FRS is able to detect deterioration over 1 year in symptomatic patients,²¹ and show that this is the case particularly in those with 'mild' and 'moderate' FTD defined by the CDR+NACCFTLD global score.

Lastly, we estimated the sample sizes required to achieve at least 80% power to detect small to moderate sized effects of a disease-modifying therapy on change in the two scales as outcome measures. The sample sizes generated for both scales, even with a moderate (30%) treatment effect, suggest that a trial entering mutation carriers at a prodromal starting point (of

CDR+NACCFTLD global rating 0.5) in an unselective way (ie, that does not further distinguish cases that are likely to soon progress) will require large numbers (with even greater numbers being required if randomisation was unequal rather than 1:1) and several years. The period in close proximity to phenocconversion is a useful target period for disease-modifying therapies, but for such a trial to require achievable sample sizes, this study suggests that better stratification will be needed, potentially combining clinical stage with neuroanatomical and/or fluid biomarkers to accurately identify likely converters. For example, a study involving GENFI and another genetic FTD cohort has recently shown that mutation carriers whose score worsens on the CDR+NACCFTLD over the next 1–2 years have high plasma neurofilament light chain concentrations at baseline compared with non-converters.³²

Limitations

By including a large number of mutation carriers at varied proximities to symptom onset, this study was able to evaluate the utility of disease staging tools across the spectrum of genetic FTD. However, the study cohort at baseline contains a larger proportion of asymptomatic than symptomatic carriers, and once stratified, individual group numbers were smaller. We took a transdiagnostic approach to the study, incorporating all phenotypes in the analysis. We, therefore, did not establish whether the scales were better at evaluating one phenotype over the other, although this is difficult as our study contained mainly people with a bvFTD phenotype (as is the case for genetic FTD), and few with PPA or FTD-ALS.²⁷ We were also not able to directly assess the ability of the scales to specifically measure the presence of prodromal symptoms as we did not have another marker of this stage, for example, clinician judgment. As discussed above, it may be that both scales (but particularly the CDR+NACCFTLD) are not sensitive enough to adequately capture this stage, and further studies should try to address this point.

CONCLUSIONS

Global rating scales such as the CDR+NACCFTLD and FRS serve a helpful purpose in clinical trials in providing a single score that can condense clinical judgement about disease severity. Although the CDR+NACCFTLD has become the most prominent clinical rating scale in FTD, there are potential issues with its use in clinical trials. In this study we show that there are similarities to the FRS as well as differences, and highlight the potential benefits for using the FRS both in clinical stratification and as an outcome measure in prevention trials of genetic FTD mutation carriers. However, both measures do not fully capture the entire spectrum of FTD symptomatology, and future improvements to the scales should consider the inclusion of motor and neuropsychiatric deficits.

Author affiliations

¹Department of Neurodegenerative Disease, University College London Dementia Research Centre, London, UK

²Department of Medical Statistics, London School of Hygiene & Tropical Medicine, London, UK

³Department of Neurology, Erasmus Medical Center, Rotterdam, The Netherlands

⁴Cognitive Disorders Unit, Department of Neurology, Hospital Universitario de Donostia, San Sebastian, Spain

⁵Neuroscience Area, Biodonostia Health Research Institute, Donostia-san Sebastian, Spain

⁶Alzheimer's Disease and Other Cognitive Disorders Unit, Neurology Service, Hospital Clínic, Institut d'Investigacions Biomèdiques August Pi I Sunyer, University of Barcelona, Barcelona, Spain

⁷Clinique Interdisciplinaire de Mémoire, Département des Sciences Neurologiques, CHU de Québec, and Faculté de Médecine, Laval University, Québec, Québec, Canada

⁸Center for Alzheimer Research, Division of Neurogeriatrics, Department of Neurobiology, Care Sciences and Society, Bioclinicum, Karolinska Institutet, Stockholm, Sweden

⁹Unit for Hereditary Dementias, Theme Aging, Karolinska University Hospital, Stockholm, Sweden

¹⁰Sunnybrook Health Sciences Centre, Sunnybrook Research Institute, University of Toronto, Toronto, Ontario, Canada

¹¹Tanz Centre for Research in Neurodegenerative Diseases, University of Toronto, Toronto, Ontario, Canada

¹²Department of Clinical Neurosciences, University of Cambridge, Cambridge, UK

¹³Neurology Unit, Department of Clinical and Experimental Sciences, University of Brescia, Brescia, Italy

¹⁴Clinical Neurological Sciences, University of Western Ontario, London, Ontario, Canada

¹⁵Dept. of Neurodegenerative Diseases, Eberhard Karls University Tübingen Hertie Institute for Clinical Brain Research, Tübingen, Germany

¹⁶Center for Neurodegenerative Diseases, DZNE, Tübingen, Germany

¹⁷Fondazione IRCCS Ca' Granda Ospedale Maggiore Policlinico, Milan, Italy

¹⁸Centro Dino Ferrari, University of Milan, Milan, Italy

¹⁹Laboratory for Cognitive Neurology, Department of Neurosciences, KU Leuven, Leuven, Belgium

²⁰Neurology Service, KU Leuven University Hospitals Leuven, Leuven, Belgium

²¹Leuven Brain Institute, KU Leuven, Leuven, Belgium

²²Faculty of Medicine, University of Lisbon, Lisbon, Portugal

²³Nuffield Department of Clinical Neurosciences, University of Oxford Medical Sciences Division, Oxford, UK

²⁴Department of Brain Sciences, Imperial College London, London, UK

²⁵Division of Neuroscience and Experimental Psychology, Wolfson Molecular Imaging Centre, The University of Manchester, Manchester, UK

²⁶Departments of Geriatric Medicine and Nuclear Medicine, University of Duisburg-Essen, Duisburg, Germany

²⁷Department of Psychiatry, McGill University Health Centre, Montreal, Québec, Canada

²⁸McConnell Brain Imaging Centre, Montreal Neurological Institute and Hospital, Montreal, Québec, Canada

²⁹Sorbonne Université, Paris Brain Institute – Institut du Cerveau – ICM, Inserm U1127, CNRS UMR 7225, Hôpital Universitaire Pitié Salpêtrière, Paris, France

³⁰Centre de référence des démences rares ou précoces, IM2A, Département de Neurologie, Hôpital Universitaire Pitié Salpêtrière, Paris, France

³¹Département de Neurologie, AP-HP - Hôpital Pitié-Salpêtrière, Paris, France

³²Fondazione IRCCS Istituto Neurologico Carlo Besta, Milano, Italy

³³University Hospital of Coimbra (HUC), Neurology Service, University of Coimbra Faculty of Medicine, Coimbra, Portugal

³⁴Center for Neuroscience and Cell Biology, University of Coimbra Faculty of Medicine, Coimbra, Portugal

³⁵University of Lille, Lille, France

³⁶CNR-MAJ, Labex Distalz, LiCEND Lille, CHU Lille, Lille, France

³⁷Inserm 1172, Lille, France

³⁸Department of Neurology, Ludwig-Maximilians-Universität München, München, Germany

³⁹German Center for Neurodegenerative Diseases, DZNE, Munich, Germany

⁴⁰Munich Cluster of Systems Neurology (SyNergy), Munich, Germany

⁴¹Department of Neurology, University of Ulm, Ulm, Germany

⁴²Department of Neurofarba, University of Florence, Firenze, Italy

⁴³IRCCS Fondazione Don Carlo Gnocchi, Firenze, Italy

Medical Biophysics, The University of Western Ontario, London, Ontario, Canada; Centre for Functional and Metabolic Mapping, Roberts Research Institute, The University of Western Ontario, London, Ontario, Canada; Benjamin Bender, Department of Diagnostic and Interventional Neuroradiology, University of Tübingen, Tübingen, Germany; Alberto Benussi, Centre for Neurodegenerative Disorders, Department of Clinical and Experimental Sciences, University of Brescia, Italy; Maxime Bertoux, Inserm 1172, Lille, France; CHU, CNR-MAJ, Labex Distalz, LiCEND Lille, France; Anne Bertrand, Sorbonne Université, Paris Brain Institute, Institut du Cerveau, ICM, Inserm U1127, CNRS UMR 7225, AP-HP, Hôpital Pitié-Salpêtrière, Paris, France; Inria, Aramis project team, F-75013, Paris, France; Centre pour l'Acquisition et le Traitement des Images, Institut du Cerveau et la Moelle, Paris, France; Valentina Bessi, Department of Neuroscience, Psychology, Drug Research, and Child Health, University of Florence, Florence, Italy; Sandra Black, Sunnybrook Health Sciences Centre, Sunnybrook Research Institute, University of Toronto, Toronto, Canada; Martina Bocchetta, Dementia Research Centre, Department of Neurodegenerative Disease, UCL Institute of Neurology, Queen Square, London, UK; Sergi Borrego-Ecija, Alzheimer's disease and Other Cognitive Disorders Unit, Neurology Service, Hospital Clínic, Barcelona, Spain; Jose Bras, Center for Neurodegenerative Science, Van Andel Institute, Grand Rapids, Michigan, MI 49503, USA; Alexis Brice, Sorbonne Université, Paris Brain Institute, Institut du Cerveau, ICM, Inserm U1127, CNRS UMR 7225, AP-HP, Hôpital Pitié-Salpêtrière, Paris, France; Reference Network for Rare Neurological Diseases (ERN-RND); Rose Bruffaerts, Laboratory for Cognitive Neurology, Department of Neurosciences, KU Leuven, Leuven, Belgium; Agnès Camuzat, Sorbonne Université, Paris Brain Institute, Institut du Cerveau, ICM, Inserm U1127, CNRS UMR 7225, AP-HP, Hôpital Pitié-Salpêtrière, Paris, France; Marta Cañada, CITA Alzheimer, San Sebastian, Gipuzkoa, Spain; Valentina Cantoni, Centre for Neurodegenerative Disorders, Neurology Unit, Department of Clinical and Experimental Sciences, University of Brescia, Brescia, Italy; Paola Caroppo, Fondazione IRCCS Istituto Neurologico Carlo Besta, Milano, Italy; David Cash, Dementia Research Centre, Department of Neurodegenerative Disease, UCL Institute of Neurology, Queen Square, London, UK; Miguel Castelo-Branco, Faculty of Medicine, University of Coimbra, Coimbra, Portugal; Olivier Colliot, Sorbonne Université, Paris Brain Institute, Institut du Cerveau, ICM, Inserm U1127, CNRS UMR 7225, AP-HP, Hôpital Pitié-Salpêtrière, Paris, France; Inria, Aramis project team, F-75013, Paris, France; Centre pour l'Acquisition et le Traitement des Images, Institut du Cerveau et la Moelle, Paris, France; Thomas Cope, Department of Clinical Neuroscience, University of Cambridge, Cambridge, UK; Vincent Deramecourt, Univ Lille, France; Inserm 1172, Lille, France; CHU, CNR-MAJ, Labex Distalz, LiCEND Lille, France; Maria de Arriba, Neuroscience Area, Biodonostia Health Research Institute, San Sebastian, Gipuzkoa, Spain; Giuseppe Di Fede, Fondazione IRCCS Istituto Neurologico Carlo Besta, Milano, Italy; Alina Diez, Neuroscience Area, Biodonostia Health Research Institute, San Sebastian, Gipuzkoa, Spain; Diana Duro, Faculty of Medicine, University of Coimbra, Coimbra, Portugal; Chiara Fenoglio, Fondazione IRCCS Ca' Granda Ospedale Maggiore Policlinico, Neurodegenerative Diseases Unit, Milan, Italy; University of Milan, Centro Dino Ferrari, Milan, Italy; Camilla Ferrari, Department of Neuroscience, Psychology, Drug Research, and Child Health, University of Florence, Florence, Italy; Catarina B. Ferreira -Laboratory of Neurosciences, Institute of Molecular Medicine, Faculty of Medicine, University of Lisbon, Lisbon, Portugal; Nick Fox, Dementia Research Centre, Department of Neurodegenerative Disease, UCL Institute of Neurology, Queen Square, London, UK; Morris Freedman, Baycrest Health Sciences, Rotman Research Institute, University of Toronto, Toronto, Canada; Giorgio Fumagalli, Fondazione IRCCS Ca' Granda Ospedale Maggiore Policlinico, Neurodegenerative Diseases Unit, Milan, Italy; University of Milan, Centro Dino Ferrari, Milan, Italy; Aurélie Funkiewiez, Centre de référence des démences rares ou précoces, IM2A, Département de Neurologie, AP-HP, Hôpital Pitié-Salpêtrière, Paris, France; Sorbonne Université, Paris Brain Institute Institut du Cerveau, ICM, Inserm U1127, CNRS UMR 7225, AP-HP, Hôpital Pitié-Salpêtrière, Paris, France; Alazne Gabilondo -Neuroscience Area, Biodonostia Health Research Institute, San Sebastian, Gipuzkoa, Spain; Roberto Gasparotti, Neuroradiology Unit, University of Brescia, Brescia, Italy; Serge Gauthier, Alzheimer Disease Research Unit, McGill Centre for Studies in Aging, Department of Neurology & Neurosurgery, McGill University, Montreal, Québec, Canada; Stefano Gazzina, Neurology, ASST Brescia Hospital, Brescia, Italy; Giorgio Giaccone, Fondazione IRCCS Istituto Neurologico Carlo Besta, Milano, Italy; Ana Gorostidi, Neuroscience Area, Biodonostia Health Research Institute, San Sebastian, Gipuzkoa, Spain; Caroline Greaves, Dementia Research Centre, Department of Neurodegenerative Disease, UCL Institute of Neurology, Queen Square, London, UK; Rita Guerreiro, Center for Neurodegenerative Science, Van Andel Institute, Grand Rapids, Michigan, MI 49503, USA; Carolin Heller, Dementia Research Centre, Department of Neurodegenerative Disease, UCL Institute of Neurology, Queen Square, London, UK; Tobias Hoegen, Neurologische Klinik, Ludwig-Maximilians-Universität München, München, Germany; Begoña Indakoechea, Cognitive Disorders Unit, Department of Neurology, Donostia University Hospital, San Sebastian, Gipuzkoa, Spain; Neuroscience Area, Biodonostia Health Research Institute, San Sebastian, Gipuzkoa, Spain; Vesna Jelic, Division of Clinical Geriatrics, Karolinska Institutet, Stockholm, Sweden; Hans-Otto Karnath, Division of Neuropsychology, Hertie-Institute for Clinical Brain Research and Center of Neurology, University of Tübingen, Tübingen, Germany; Ron Keren -The University

Twitter Georgia Peakman @georgia_peakman and Simon Ducharme @sducharme66

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Collaborators Genetic FTD Initiative (GENFI): Sónia Afonso, Instituto Ciencias Nucleares Aplicadas a Saude, Universidade de Coimbra, Coimbra, Portugal; Maria Rosário Almeida, Faculty of Medicine, University of Coimbra, Coimbra, Portugal; Sarah Anderl-Straub, Department of Neurology, University of Ulm, Ulm, Germany; Christin Andersson, Department of Clinical Neuroscience, Karolinska Institutet, Stockholm, Sweden; Anna Antonell, Alzheimer's disease and Other Cognitive Disorders Unit, Neurology Service, Hospital Clínic, Barcelona, Spain; Silvana Archetti, Biotechnology Laboratory, Department of Diagnostics, ASST Brescia Hospital, Brescia, Italy; Andrea Arighi, Fondazione IRCCS Ca' Granda Ospedale Maggiore Policlinico, Neurodegenerative Diseases Unit, Milan, Italy; University of Milan, Centro Dino Ferrari, Milan, Italy; Mircea Balasa, Alzheimer's disease and Other Cognitive Disorders Unit, Neurology Service, Hospital Clínic, Barcelona, Spain; Myriam Barandiaran, Cognitive Disorders Unit, Department of Neurology, Donostia University Hospital, San Sebastian, Gipuzkoa, Spain; Neuroscience Area, Biodonostia Health Research Institute, San Sebastian, Gipuzkoa, Spain; Nuria Bargalló, Imaging Diagnostic Center, Hospital Clínic, Barcelona, Spain; Robart Bartha, Department of

Health Network, Toronto Rehabilitation Institute, Toronto, Canada; Gregory Kuchcinski, Univ Lille, France; Inserm 1172, Lille, France; CHU, CNR-MAJ, Labex Distalz, LiCEND Lille, France; Tobias Langheinrich, Division of Neuroscience and Experimental Psychology, Wolfson Molecular Imaging Centre, University of Manchester, Manchester, UK; Manchester Centre for Clinical Neurosciences, Department of Neurology, Salford Royal NHS Foundation Trust, Manchester, UK; Thibaud Leboviev, Univ Lille, France; Inserm 1172, Lille, France; CHU, CNR-MAJ, Labex Distalz, LiCEND Lille, France; Maria João Leitão, Centre of Neurosciences and Cell Biology, Universidade de Coimbra, Coimbra, Portugal; Albert Lladó, Alzheimer's disease and Other Cognitive Disorders Unit, Neurology Service, Hospital Clinic, Barcelona, Spain; Gemma Lombardi, Department of Neuroscience, Psychology, Drug Research and Child Health, University of Florence, Florence, Italy; Sandra Loosli -Neurologische Klinik, Ludwig-Maximilians-Universität München, Munich, Germany; Carolina Maruta, Laboratory of Language Research, Centro de Estudos Egas Moniz, Faculty of Medicine, University of Lisbon, Lisbon, Portugal; Simon Mead, MRC Prion Unit, Department of Neurodegenerative Disease, UCL Institute of Neurology, Queen Square, London, UK; Lieke Meeter, Department of Neurology, Erasmus Medical Center, Rotterdam, Netherlands; Gabriel Miltenberger, Faculty of Medicine, University of Lisbon, Lisbon, Portugal; Rick van Minkelen, Department of Clinical Genetics, Erasmus Medical Center, Rotterdam, Netherlands; Sara Mitchell, Sunnybrook Health Sciences Centre, Sunnybrook Research Institute, University of Toronto, Toronto, Canada; Katrina Moore, Dementia Research Centre, Department of Neurodegenerative Disease, UCL Institute of Neurology, Queen Square, London, UK; Benedetta Nacmias, Department of Neuroscience, Psychology, Drug Research and Child Health, University of Florence, Florence, Italy; Annabel Nelson, Dementia Research Centre, Department of Neurodegenerative Disease, UCL Institute of Neurology, Queen Square, London, UK; Linn Öjertstedt, Center for Alzheimer Research, Division of Neurogeriatrics, Department of Neurobiology, Care Sciences and Society, Bioclinicum, Karolinska Institutet, Solna, Sweden; Unit for Hereditary Dementias, Theme Aging, Karolinska University Hospital, Solna, Sweden; Jaume Olives, Alzheimer's disease and Other Cognitive Disorders Unit, Neurology Service, Hospital Clinic, Barcelona, Spain; Sebastien Ourselin, School of Biomedical Engineering & Imaging Sciences, King's College London, London, UK; Alessandro Padovani, Centre for Neurodegenerative Disorders, Department of Clinical and Experimental Sciences, University of Brescia, Italy; Jessica Panman, Department of Neurology, Erasmus Medical Center, Rotterdam, Netherlands; Janne M. Pappa, Department of Neurology, Erasmus Medical Center, Rotterdam; Yolande Pijnenburg, Amsterdam University Medical Centre, Amsterdam VUmc, Amsterdam, Netherlands; Cristina Polito, Department of Biomedical, Experimental and Clinical Sciences "Mario Serio", Nuclear Medicine Unit, University of Florence, Florence, Italy; Enrico Premi, Stroke Unit, ASST Brescia Hospital, Brescia, Italy; Sara Prioni, Fondazione IRCCS Istituto Neurologico Carlo Besta, Milano, Italy; Catharina Prix -Neurologische Klinik, Ludwig-Maximilians-Universität München, Munich, Germany; Rosa Rademakers [as London Ontario geneticist], Department of Neurosciences, Mayo Clinic, Jacksonville, Florida, USA; Veronica Redaelli -Fondazione IRCCS Istituto Neurologico Carlo Besta, Milano, Italy; Daisy Rinaldi, Centre de référence des démences rares ou précoces, IM2A, Département de Neurologie, AP-HP, Hôpital Pitié-Salpêtrière, Paris, France; Sorbonne Université, Paris Brain Institute Institut du Cerveau, ICM, Inserm U1127, CNRS UMR 7225, AP-HP, Hôpital Pitié-Salpêtrière, Paris, France; Département de Neurologie, AP-HP, Hôpital Pitié-Salpêtrière, Paris, France; Reference Network for Rare Neurological Diseases (ERN-RND); Tim Rittman, Department of Clinical Neurosciences, University of Cambridge, Cambridge, UK; Ekaterina Rogaeva -Tanz Centre for Research in Neurodegenerative Diseases, University of Toronto, Toronto, Canada; Adeline Rollin, CHU, CNR-MAJ, Labex Distalz, LiCEND Lille, France; Pedro Rosa-Neto -Translational Neuroimaging Laboratory, McGill Centre for Studies in Aging, McGill University, Montreal, Québec, Canada; Giacomina Rossi, Fondazione IRCCS Istituto Neurologico Carlo Besta, Milano, Italy; Martin Rössor, Dementia Research Centre, Department of Neurodegenerative Disease, UCL Institute of Neurology, Queen Square, London, UK; Beatriz Santiago, Neurology Department, Centro Hospitalar e Universitario de Coimbra, Coimbra, Portugal; Dario Saracino, Sorbonne Université, Paris Brain Institute, Institut du Cerveau, ICM, Inserm U1127, CNRS UMR 7225, AP-HP, Hôpital Pitié-Salpêtrière, Paris, France; Inria, Aramis project team, F-75013, Paris, France; Centre de référence des démences rares ou précoces, IM2A, Département de Neurologie, AP-HP, Hôpital Pitié-Salpêtrière, Paris, France; Sabrina Sayah, Sorbonne Université, Paris Brain Institute, Institut du Cerveau, ICM, Inserm U1127, CNRS UMR 7225, AP-HP, Hôpital Pitié-Salpêtrière, Paris, France; Elio Scarpini, Fondazione IRCCS Ca' Granda Ospedale Maggiore Policlinico, Neurodegenerative Diseases Unit, Milan, Italy; University of Milan, Centro Dino Ferrari, Milan, Italy; Sonja Schönecker, Neurologische Klinik, Ludwig-Maximilians-Universität München, Munich, Germany; Harro Seelaar, Department of Neurology, Erasmus Medical Center, Rotterdam, Netherlands; Elisa Semler -Department of Neurology, University of Ulm, Ulm; Rachelle Shafei, Dementia Research Centre, Department of Neurodegenerative Disease, UCL Institute of Neurology, Queen Square, London, UK; Christen Shoemaker, Department of Clinical Neurological Sciences, University of Western Ontario, London, Ontario, Canada; Imogen Swift, Department of Neurodegenerative Disease, Dementia Research Centre, UCL Institute of Neurology, Queen Square, London, UK; Miguel Tábuas-Pereira, Neurology Department, Centro Hospitalar e

Universitario de Coimbra, Coimbra, Portugal; Mikel Tainta, Neuroscience Area, Biodonostia Health Research Institute, San Sebastian, Gipuzkoa, Spain; Ricardo Taipa, Neuropathology Unit and Department of Neurology, Centro Hospitalar do Porto, Hospital de Santo António, Oporto, Portugal; David Tang-Wai -The University Health Network, Krembil Research Institute, Toronto, Canada; David L Thomas, Neuroimaging Analysis Centre, Department of Brain Repair and Rehabilitation, UCL Institute of Neurology, Queen Square, London, UK; Paul Thompson, Division of Neuroscience and Experimental Psychology, Wolfson Molecular Imaging Centre, University of Manchester, Manchester, UK; Hakan Thonberg, Center for Alzheimer Research, Division of Neurogeriatrics, Karolinska Institutet, Stockholm, Sweden; Carolyn Timberlake, Department of Clinical Neurosciences, University of Cambridge, Cambridge, UK; Pietro Tiraboschi, Fondazione IRCCS Istituto Neurologico Carlo Besta, Milano, Italy; Emily Todd, Dementia Research Centre, Department of Neurodegenerative Disease, UCL Institute of Neurology, UK; Philip Van Damme, Neurology Service, University Hospitals Leuven, Belgium; Laboratory for Neurobiology, VIB-KU Leuven Centre for Brain Research, Leuven, Belgium; Mathieu Vandenbulcke, Geriatric Psychiatry Service, University Hospitals Leuven, Belgium; Neuropsychiatry, Department of Neurosciences, KU Leuven, Leuven, Belgium; Michele Veldsman, Nuffield Department of Clinical Neurosciences, Medical Sciences Division, University of Oxford, Oxford, UK; Ana Verdelho, Department of Neurosciences and Mental Health, Centro Hospitalar Lisboa Norte, Hospital de Santa Maria & Faculty of Medicine, University of Lisbon, Lisbon, Portugal; Jorge Villanua, OSATEK, University of Donostia, San Sebastian, Gipuzkoa, Spain; Jason Warren, Dementia Research Centre, Department of Neurodegenerative Disease, UCL Institute of Neurology, Queen Square, London, UK; Carlo Wilke, Department of Neurodegenerative Diseases, Hertie-Institute for Clinical Brain Research and Center of Neurology, University of Tübingen, Tübingen, Germany; Center for Neurodegenerative Diseases (DZNE), Tübingen, Germany; Ione Woollacott, Dementia Research Centre, Department of Neurodegenerative Disease, UCL Institute of Neurology, Queen Square, London, UK; Elisabeth Wlasic, Neurologische Klinik, Ludwig-Maximilians-Universität München, Munich, Germany; Henrik Zetterberg, Dementia Research Institute, Department of Neurodegenerative Disease, UCL Institute of Neurology, Queen Square, London, UK; Miren Zulaica, Neuroscience Area, Biodonostia Health Research Institute, San Sebastian, Gipuzkoa, Spain.

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ORCID iDs

Georgia Peakman <http://orcid.org/0000-0002-3319-138X>
 Rhian S Convery <http://orcid.org/0000-0002-9477-1812>
 John C Van Swieten <http://orcid.org/0000-0001-6278-6844>
 Lize C Jiskoot <http://orcid.org/0000-0002-1120-1858>
 James B Rowe <http://orcid.org/0000-0001-7216-8679>
 Barbara Borroni <http://orcid.org/0000-0001-9340-9814>
 Elizabeth Finger <http://orcid.org/0000-0003-4461-7427>
 Daniela Galimberti <http://orcid.org/0000-0002-9284-5953>
 Alex Gerhard <http://orcid.org/0000-0002-8071-6062>
 Simon Ducharme <http://orcid.org/0000-0002-7309-1113>
 Isabelle Le Ber <http://orcid.org/0000-0002-2508-5181>
 Adrian Danek <http://orcid.org/0000-0001-8857-5383>
 Markus Otto <http://orcid.org/0000-0002-6647-5944>
 Sandro Sorbi <http://orcid.org/0000-0002-0380-6670>
 Jonathan D Rohrer <http://orcid.org/0000-0002-6155-8417>

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